LASER POWER GRID

FIELD AND BACKGROUND OF THE INVENTION

5   The present invention relates to data networks, employing WDM multiplexing, and incorporating wavelength addressing, and in particular, to a laser power grid, for operation with these networks.

Communication traffic is steadily increasing, both in size and in complexity. Leading service providers for Internet Protocol (IP), for example, report a 300 percent

10   growth per year in Internet traffic, while traditional voice traffic has grown at a about 13 percent.   [Cisco documentation, of Sep 28 05:50:55 PDT 2002, www.cisco.com/univercd/cc/td/doc/product/mels/cm1500/dwdm/dwdm_fns.htm]. In response to this explosive growth in bandwidth demand, long-haul service providers are moving away from Time division multiplexing (TDM) based systems, which were

15   optimized for voice but now prove to be inefficient, to wavelength division multiplexing (WDM).

TDM was invented as a way of maximizing the amount of voice traffic over a medium by multiplexing, so that more than one telephone call could be put on a single link.   In essence, TDM increases the capacity of a transmission link by slicing time

20   into smaller intervals, so that the bits from multiple input sources can be carried on the link, thus, increasing the number of bits transmitted per second.

Using TDM, data may be transmitted at 10 Gbps and recent advances have resulted in speeds of 40 Gbps. Yet, the electronic circuitry that makes this possible is complex and costly.   Furthermore, technical issues, such as chromatic dispersion and

25   nonlinear effects that can affect waveform quality, may restrict the applicability of TDM at these rates.

An alternative to TDM, wavelength division multiplexing (WDM) now reigns as the leading technologies for transmitting high volume of data traffic over long distances. It is based on the inherent advantage of photons as data carriers, which is

30   that photons of different wavelengths do not normally interact, thus enabling the transmission of many channels of data, in parallel, in a single fiber, with photons of a different wavelengths acting as channels.   WDM uses single-mode fiber to carry multiple light waves of differing frequencies.

In a sense, multiplexing by WDM is analogous to radio broadcasting on different wavelengths. Each channel is transmitted at a different frequency, and one can select a frequency, as if by using a tuner.

Thus, in WDM, many wavelengths are combined onto a single fiber, so as to simultaneously multiplex signals of 2.5 to 40 Gbps each over a strand of fiber. In this manner, the effective capacity of existing fiber infrastructure can be increased by a factor of up to 100.

When using WDM, each of the wavelengths is launched into the fiber, at the transmitting end, and the signals are demultiplexed by an optical wavelength demultiplexer, at the receiving end. As with TDM, the resulting capacity is an aggregate of the input signals. But an important difference between TDM and WDM is that WDM carries each input signal independently of the others. In other words, each wavelength channel has its own dedicated bandwidth; all signals arrive independently, rather than being broken up and carried in time slots.

Dense wavelength division multiplexing (DWDM) is different form WDM mainly in degree. DWDM spaces the wavelengths more closely than WDM; in consequence, it has a greater overall capacity. DWDM systems with 100 channels per fiber each carrying 10Gb/sec are commercially available, enabling data traffic at a rate of approximately 1 Terabit per second in a single fiber. The spacing limit is not precisely known yet, and has probably not been reached. The state of art of commercial systems is 50 GHz.

Similarly, coarse wavelength division multiplexing (CWDM) relates to spacing the wavelengths sparsely, thus reducing the cost of the systems.

The capability of two optical signals of different wavelengths to occupy the same fiber, at the same time, makes WDM point-to-point segments extraordinarily powerful. The challenge is how to harness this capability to supply the huge bandwidth that flows in high performance computing systems that are predominantly a complex mesh of parallel interconnections. In particular it is desirable to combine the inherent advantages of the packet/burst-switching paradigm with the vast data transfer capability of the optical fiber.

An added feature when using WDM is the possibility of using the channel wavelength as an address vehicle for delivering the transmissions to their destinations. This idea is termed wavelength addressing.

Wavelength addressing relates to assigning every processing element (PE), or node, in a data network a wavelength, as a receiving address. The processing element, or node, may be a chip, a board, a cabinet, or even a routing switch. A schematic illustration of a PE adapted for wavelength addressing is provided in Figure

5   1A.

As seen in Figure 1A, a PE 10 includes a processing unit 30, a transmitter 20 and a wavelength addressed receiver $90[\lambda_0]$. Processing unit 30 communicates to transmitter 20 an information defined by E_i ; λ_i, wherein E_i relates to an electronic data to be transmitted, and λ_i is the address of the receiving PE, at a specific instant. It will

10   be appreciated that the information defined by E_i ; λ_i relates to a specific transmittal. A moment later, processing unit 30 may communicate to transmitter 20 an information defined by E_n ; λ_n.

Transmitter 20 communicates the wavelength designation λ_i to a tunable laser 40 which produces a light propagation of wavelength λ_i. Additionally, transmitter 20

15   communicates the electronic data E_i to a modulator 60, which modulates the light propagation of wavelength λ_i so as to produce a data packet $50_i;\lambda_i$ containing electronic information E_i and addressed to a PE whose receiving address is λ_i.

When information is received, wavelength addressed receiver $90[\lambda_0]$ communicates the received data, for example, $59_n;\lambda_0$, to processing unit 30.

20   Figure 1B illustrates a data network 150 having a plurality of PEs of the type described in Figure 1A, denoted, PE 12, PE 14, PE 15, PE 16, and PE 18, having processing units 32, 34, 35, 36, and 38, respectively, transmitters 22, 24, 25, 26, and 28, respectively, tunable lasers, 42, 44, 45, 46, and 48, respectively, modulators 62, 64, 65, 66, and 68, respectively, and wavelength addressed receivers $92[\lambda_5]$, $94[\lambda_6]$,

25   $95[\lambda_4]$, $96[\lambda_8]$, and $98[\lambda_2]$, respectively, the wavelength addressed receivers communicating their received data to processing units 32, 34, 35, 36, and 38, respectively.

Accordingly, a plurality of data packets, $52_i;\lambda_2$, $54_i;\lambda_4$, $55_i;\lambda_5$, $56_i;\lambda_6$, and $58_i;\lambda_8$, each issuing from its respective PE, are coupled to an optical coupler 70 and

30   transmitted, by WDM.

An optical-wavelength demultiplexer 80 decouples the data packets by wavelengths, and each is routed to its wavelength address.

It will be appreciated that by coupling the data packets to a single fiber, each PE needs to communicate only with optical coupler 70 and optical-wavelength demultiplexer 80, rather than with all the other PEs.

Additionally, the use of wavelength addressing reduces the electronic information that needs to be contained in the data packet.

The architecture of Figures 1A and 1B relies heavily on the performance and price of the tunable lasers; in fact, a major incentive for the development of tunable lasers is their application for wavelength multiplexing and addressing. Yet, tunable lasers are expensive, cumbersome, and slow, and their use limits scalability.

Rubin et al., (S. Rubin, E., Buimovich, G. Ingber and D. Sadot, "Implementation of an Ultra-Fast Widely-Tunable Burst-Mode 10 Gbps Transceiver," Electronic Letters vol. 38 No. 23 pp. 1462 – 1463, Nov., 2002) describe a tunable 10Gbps transceiver, for optical burst-switching applications. The burst-mode receiver has fast tuning of less then 50 nano-seconds between 80 channels over the entire C-band, together with fast locking, of less than 100 nanosecond.

Faster tunable lasers are under development; however, their projected performance and price may not justify their deployment in computer networks with multitude of nodes, in particular for board-to-board and chip-to-chip communication.

As a consequence, the range of applications implemented by tunable lasers is limited to networks in which the price of each node is high, and the length of the burst is comparatively long.

There is thus a widely recognized need for, and it would be highly advantageous to have WDM systems which implement wavelength addressing, devoid of the above limitations.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, there is provided a laser power grid, comprising:

a first plurality of continuous-work (cw) laser sources, for generating a first plurality of light propagations, each light propagation being distinct by its wavelength;

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a laser distribution grid, formed as at least one optical fiber, optically coupled to the first plurality of laser sources, for transmitting the first plurality of light propagations; and

a second plurality of optical-switch arrays, each array comprising at least one optical switch, coupled to the laser distribution grid, and adapted for deflecting a single one of the light propagations of a distinct wavelength, responsive to an input signal.

In accordance with an additional aspect of the present invention, the laser distribution grid is formed as a plurality of optical fibers.

In accordance with an additional aspect of the present invention, the laser distribution grid is formed as a multi-mode fiber.

Alternatively, the laser distribution grid is formed as a single-mode fiber.

In accordance with an additional aspect of the present invention, the at least one optical switch is an electroholographic switch.

In accordance with an additional aspect of the present invention, the at least one optical switch is operative by electric field multiplexing (EFM).

Alternatively, the optical-switch array includes a plurality of optical switches, equal to the first plurality of light propagations, each optical switch being optically coupled to the laser distribution grid, and each optical switch being adapted for deflecting a single one of the light propagations of the distinct wavelength, responsive to the input signal.

In accordance with an additional aspect of the present invention, the a laser distribution grid is formed as one optical fiber, which is coupled to the first plurality of optical switches, with an optical wavelength demultiplexer upstream of the optical-switch array and an optical coupler downstream of the optical-switch array.

In accordance with an additional aspect of the present invention, the laser power grid comprises an optical coupler for coupling optical fibers along the deflected course of the light propagation.

In accordance with an additional aspect of the present invention, the each optical switch is adapted to deflect a predetermined portion of the single light propagation of the distinct wavelength.

In accordance with an additional aspect of the present invention, the laser sources are fixed-wavelength laser sources.

Alternatively, the laser sources are tunable laser sources.

In accordance with another aspect of the present invention, there is provided a data network, comprising:

a laser power grid, which comprises:

a first plurality of continuous-work (cw) laser sources, for generating a first plurality of light propagations, each light propagation being distinct by its wavelength;

a laser distribution grid, formed as at least one optical fiber, optically coupled to the first plurality of laser sources, for transmitting the first plurality of light propagations; and

a second plurality of optical-switch arrays, each array comprising at least one optical switch, coupled to the laser distribution grid, and adapted for deflecting a single one of the light propagations of a distinct wavelength, responsive to an input signal;

a second plurality of Processing elements (PEs), each electronically coupled to one of the second plurality of optical-switch arrays, for providing the input signal, for deflecting the single light propagation of the distinct wavelength; and

a second plurality of optical modulators, each electronically coupled to one of the second plurality of PEs and optically coupled to the one of the optical-switch arrays, associated with the PE, for modulating the single light propagation of the distinct wavelength, responsive to an electronic information of the PE, for forming an optical data packet of a distinct wavelength for transmission, associated with the PE.

Additionally, the data network is adapted for single-wavelength data transmission.

Alternatively, the network is adapted for wavelength division multiplexing (WDM), and comprises an optical coupler, for receiving data packets from the modulators and for coupling the data packets to an optical fiber.

Additionally, the WDM is a coarse wavelength division multiplexing (CWDM).

Alternatively, the WDM is a dense wavelength division multiplexing (DWDM).

In accordance with an additional aspect of the present invention, the data network comprises a demultiplexer, optically coupled to the optical fiber for decoupling the data packets, in accordance with their wavelengths.

In accordance with an additional aspect of the present invention, the data
5   network comprises wavelength addressing, wherein each of the optical data packets is routed to a receiving PE, as determined by the distinct wavelength of the optical data packet.

In accordance with an additional aspect of the present invention, any one of the second plurality of PEs may be assigned a wavelength address and may act as the
10   receiving PE.

In accordance with an additional aspect of the present invention, the second plurality is less than or equal to the first plurality, and each of the second plurality of PEs is assigned a wavelength address.

In accordance with an additional aspect of the present invention, the second
15   plurality of PEs is arranged in a U plurality clusters, for a multi-cluster design, the data network comprises:

a second plurality of routing switches, each electronically coupled to one of the second plurality of PEs, for receiving an input signal therefrom, and each optically coupled to an output of one of the second plurality of optical modulators, for routing
20   data packets issuing from the optical modulators to a U^2 plurality of output optical couplers, responsive to the input signals from the PEs; each of the U^2 plurality of output optical couplers being designated by an output cluster and an input cluster, and

a U plurality of input optical couplers, for coupling data packets arriving in the U^2 plurality of output optical couplers to a U plurality of optical fibers, each
25   designated by an input cluster.

In accordance with an additional aspect of the present invention, the data network comprises a U plurality of demultiplexers, each optically coupled to one of the U plurality of optical fibers, for decoupling the data packets, in accordance with their wavelengths.

30   In accordance with an additional aspect of the present invention, the second plurality is less than or equal to the first plurality times the U, and each of the second plurality of PEs is assigned an address by wavelength and cluster.

In accordance with an additional aspect of the present invention, the U plurality of clusters is distributed among different locations.

In accordance with an additional aspect of the present invention, the second plurality of PEs is distributed among a Q plurality of locations, the data network comprises:

a Q plurality of output optical couplers, for coupling a plurality of data packets to be transmitted from each location to a Q plurality of output optical fibers;

an overall optical coupler, for coupling the Q plurality of output optical fibers to a single, overall fiber;

a demultiplexer, optically coupled to the single, overall fiber, for decoupling the data packets, in accordance with their wavelengths.

In accordance with an additional aspect of the present invention, the data network comprises a Q plurality of input optical couplers, for coupling a plurality of data packets heading to the Q plurality of locations, into a Q plurality of input optical fibers, each leading to one location, the coupling being based on wavelength addresses of PEs in each location.

In accordance with an additional aspect of the present invention, the data network comprises a Q plurality of input demultiplexers, each optically coupled to one of the input optical fibers, for decoupling the data packets, in accordance with their wavelengths.

In accordance with an additional aspect of the present invention, the laser distribution grid is formed as a plurality of optical fibers.

In accordance with an additional aspect of the present invention, the laser distribution grid is formed as a multi-mode fiber.

Alternatively, the laser distribution grid is formed as a single-mode fiber.

In accordance with an additional aspect of the present invention, the at least one optical switch is an electroholographic switch.

In accordance with an additional aspect of the present invention, the at least one optical switch is operative by electric field multiplexing (EFM).

Alternatively, the optical-switch array includes a plurality of optical switches, equal to the first plurality of light propagations, each optical switch being optically coupled to the laser distribution grid, and each optical switch being adapted for

deflecting a single one of the light propagations of the distinct wavelength, responsive to the input signal.

In accordance with an additional aspect of the present invention, the a laser distribution grid is formed as one optical fiber, which is coupled to the first plurality of optical switches, with an optical wavelength demultiplexer upstream of the optical-switch array and an optical coupler downstream of the optical-switch array.

In accordance with an additional aspect of the present invention, the data network comprises an optical coupler for coupling optical fibers along the deflected course of the light propagation.

In accordance with an additional aspect of the present invention, the each optical switch is adapted to deflect a predetermined portion of the single light propagation of the distinct wavelength.

In accordance with an additional aspect of the present invention, the laser sources are fixed-wavelength laser sources.

Alternatively, the laser sources are tunable laser sources.

In accordance with another aspect of the present invention, there is provided a method of WDM transmission, incorporating wavelength addressing between a plurality of PEs, distributed among Q locations, comprising:

at each location, coupling a plurality of data packets issuing from the location to a Q plurality of output optical fibers, each leading to a central location;

at the central location, coupling data packets arriving in the Q plurality of output optical fibers to a central optical fiber;

at the central location, optically demultiplexing, by wavelength, data packets issuing from the central optical fiber;

at the central location, coupling data packets which have been optically demultiplexed, by wavelength, to a Q plurality of input optical fibers, each leading to one of the Q locations, the coupling being based on wavelength addressing; and

at each locations, optically demultiplexing, by wavelength, data packets issuing from the input optical fibers, in accordance with their wavelengths.

In accordance with another aspect of the present invention, there is provided a method of WDM transmission, incorporating wavelength addressing between a plurality of PEs, in a multi-cluster data network, of U clusters, comprising:

at each cluster, routing a plurality of data packets issuing from the cluster to a U^2 plurality of output optical couplers, each output optical coupler being designated by two variables: output an input clusters;

coupling the plurality of data packets routed to each coupler to a U^2 plurality of output optical fibers, associated with the U^2 plurality of optical couplers, each output optical fiber being designated by the two variables: output an input clusters;

coupling data packets arriving in the U^2 plurality of output optical fibers to a U plurality of input optical fibers, the coupling being done by wavelength addressing, each input optical fiber being designated by an input cluster, and each leading to the cluster of its designation;

at each cluster, optically demultiplexing, by wavelength, data packets issuing from the input optical fibers, in accordance with their wavelengths.

In accordance with another aspect of the present invention, there is provided a method of data transmitting, comprising:

providing a laser power grid, which comprises:

a first plurality of continuous-work (cw) laser sources, for generating a first plurality of light propagations, each light propagation being distinct by its wavelength;

a laser distribution grid, formed as at least one optical fiber, optically coupled to the first plurality of laser sources, for transmitting the first plurality of light propagations; and

a second plurality of optical-switch arrays, each array comprising at least one optical switch, coupled to the laser distribution grid, and adapted for deflecting a single one of the light propagations of a distinct wavelength, responsive to an input signal;

electronically coupling a second plurality of PEs to the second plurality of optical-switch arrays, each PE being adapted to provide the input signal, for deflecting the single light propagation of the distinct wavelength, associated with the each PE; and

modulating the single light propagation of the distinct wavelength, responsive to an electronic information of the each PE, for forming an optical data packet of a distinct wavelength for transmission, associated with the each PE.

In accordance with another aspect of the present invention, there is provided a laser power grid, comprising:

a first plurality of continuous-work (cw) laser sources, for generating a first plurality of light propagations, each light propagation being distinct by its wavelength;

a laser distribution grid, formed as at least one optical fiber, optically coupled to the first plurality of laser sources, for transmitting the first plurality of light propagations; and

a second plurality of optical-switch arrays, each array comprising at least one optical switch, coupled to the laser distribution grid, and each array being adapted for deflecting a plurality of light propagations, responsive to an input signal.

The present invention relates to a laser power grid, for operation with data networks, employing WDM multiplexing, and incorporating wavelength addressing. The laser power grid includes a laser power supply station, comprising a plurality of continuous-work laser sources; a laser distribution grid, formed as an optical fiber, or as a plurality of optical fibers, for distributing light propagations of different wavelengths throughout a data network, to supply it with laser power; and an optical switching network, coupled to the laser distribution grid, for turning the laser power on, locally, where it is needed. The laser power grid replaces systems of tunable lasers in known data networks; it is considerably faster and cheaper than systems of tunable lasers and produces less waste heat within the data network surroundings. The laser power grid incorporates parallel fast optical communication in complex multi-node communication and computer networks and enables the implementation of burst switching and packet switching by wavelength addressing. It is particularly cost effective as the routing paradigm in inter-chip, inter-board, and inter-cabinet applications, as well as between distant sites, in a wide spectrum of applications, in both the telecom and datacom arenas.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. In case of conflict, the

patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

5   The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and

10   readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

15   In the drawings:

FIGs. 1A and 1B schematically illustrates a data network, employing WDM multiplexing, and incorporating wavelength addressing, using tunable lasers, as known in the art;

FIGs. 2A – 2H schematically illustrate a laser power grid, in accordance with

20   the present invention;

FIGs. 3A and 3B schematically illustrates a data network, employing WDM multiplexing, and incorporating wavelength addressing, using a laser power grid, in accordance with a preferred embodiment of the present invention;

FIG. 4 schematically illustrates a data network, employing WDM

25   multiplexing, and incorporating wavelength addressing, between different locations;

FIGs. 5A and 5B schematically illustrate a multi-cluster data network, employing WDM multiplexing, and incorporating wavelength addressing, using a laser power grid, in accordance with the present invention; and

FIGs. 6A and 6B schematically illustrate an electroholographic switch, in

30   accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a laser power grid, for operation with data networks, employing WDM multiplexing, and incorporating wavelength addressing. Specifically, the laser power grid includes a laser power supply station, comprising a

5   plurality of continuous-work laser sources; a laser distribution grid, formed as an optical fiber, or as a plurality of optical fibers, for distributing light propagations of different wavelengths throughout a data network, to supply it with laser power; and an optical switching network, coupled to the laser distribution grid, for turning the laser power on, locally, where it is needed. The laser power grid replaces systems of

10   tunable lasers in known data networks; it is considerably faster and cheaper than systems of tunable lasers and produces less waste heat within the data network surroundings. The laser power grid incorporates parallel fast optical communication in complex multi-node communication and computer networks and enables the implementation of burst switching and packet switching by wavelength addressing. It

15   is particularly cost effective as the routing paradigm in inter-chip, inter-board, and inter-cabinet applications, as well as between distant sites, in a wide spectrum of applications, in both the telecom and datacom arenas.

The principles and operation of the laser power grid, according to the present invention, may be better understood with reference to the drawings and accompanying

20   descriptions.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other

25   embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Referring now to the drawings, Figures 2A – 2H schematically illustrate a laser power grid 100, in accordance with the present invention.

30   Preferably, laser power grid 100 is operable with data networks, which employ WDM multiplexing, preferably also incorporating wavelength addressing, thus eliminating the need for a tunable laser to be associated with each processing element (PE).

Laser power grid 100 includes a laser power supply station 110, which includes a plurality M of continuous-work (cw) laser sources, 112, 114, 115, 116, and 118, each producing a light propagation of a specific wavelength λ_2, λ_4, λ_5, λ_6, and λ_8, respectively.

5   Preferably, laser sources 112, 114, 115, 116, and 118 are fixed wavelength laser sources. Alternatively, they may be tunable lasers.

Additionally, laser power grid 100 includes a laser distribution grid 130, which issues from laser power supply station 110, preferably, as a single optical fiber 130 (Figures 2D – 2G), for distributing light propagations of wavelengths λ_2, λ_4, λ_5, 10 λ_6, and λ_8, respectively, to a data network, to supply it with laser power. Alternatively, as seen in Figures 2A – 2C, a plurality of optical fibers 132, 134, 135, 136, and 138 may be used. The single optical fiber or the plurality of optical fibers may be single-mode or multimode fibers.

Furthermore, laser power grid 100 includes an optical switching network 140, 15   coupled to laser distribution grid 130, for turning the laser power on, locally, where it is needed.

Optical switching network 140 includes a plurality N of optical-switch arrays, 142, 144, 145, 146, and 148, each serving a PE, or node. Thus the number of optical-switch arrays should equal the number of PEs in the data network.

20   Additionally, as seen in Figures 2B – 2E, each optical-switch array, such as optical-switch array 142, or an example optical-switch array 120, may include a plurality M of optical switches, 122, 124, 125, 126, and 128, M being the number of light propagations which are distributed by laser power grid 100. The optical switches are coupled to laser distribution grid 130.

25   Several geometries may be employed for coupling laser distribution grid 130 to optical switch array 120, comprising optical switches, 122, 124, 125, 126, and 128.

Figures 2A - 2C illustrate a situation in which laser distribution grid 130 includes optical fibers 132, 134, 135, 136, 138, each transmitting a single light propagation, and each coupled to a single optical switch, the switch being adapted to 30   deflect the light propagation carried by the optical fiber. Thus, optical fibers 132, 134, 135, 136, and 138 are coupled to optical switches 122, 124, 125, 126, and 128 respectively, for deflecting light propagations of wavelengths λ_2, λ_4, λ_5, λ_6, and λ_8, respectively, responsive to input signals.

As Figures 2A - 2C illustrate, electric switches 162, 164, 165, 166, and 168 provide individual control to optical switches 122, 124, 125, 126, and 128, respectively. At a certain moment, array 120 may respond to an input signal to optical switch 125, deflecting the light propagation of wavelength λ_5, as seen in

5 Figure 2C. At another moment, array 120 may respond to an input signal to optical switch 128, deflecting the light propagation of wavelength λ_8.

As will be described hereinbelow, in conjunction with Figures 6A and 6B, only a portion f_1 of the light propagation may be deflected, while a second portion f_2 may continue to power the data network.

10 Preferably, optical switches, 122, 124, 125, 126, and 128 are electroholographic switches.

Figure 2D schematically illustrates a preferred geometry for coupling laser distribution grid 130 to optical switch array 120, comprising optical switches, 122, 124, 125, 126, and 128, wherein laser distribution grid 130 is arranged in a single

15 optical fiber and optical switches 122, 124, 125, 126, and 128 are electroholographic switches.

Upstream of optical switch array 120, an optical wavelength demultiplexer decouples the light propagations of optical fiber 130 to individual wavelengths, and each light propagation is routed to the electroholographic switch of the corresponding

20 wavelength. Preferably the holograms are latent, activated by the application of an electric field. As seen in Figure 2D, electroholographic switch 125 is activated, deflecting the light propagation of wavelength λ_5 to the PE associated with the optical switch array.

The other light propagations continue undeleted to a coupler 123, for coupling

25 to optical fiber 130.

It will be appreciated that although the deflected light propagation of wavelength λ_5 may pass through other electroholographic switches on its deflected course, for example, electroholographic switches 124 and 122 as seen in Figure 2D, these do not affect it, as they are adapted for other wavelengths.

30 Figure 2E schematically illustrates another geometry for coupling laser distribution grid 130 to optical switch array 120, comprising optical switches, 122, 124, 125, 126, and 128, wherein laser distribution grid 130 is arranged in a single

optical fiber, wherein optical switches 122, 124, 125, 126, and 128 are analog optical switches.

The essential difference between the present embodiment and that of Figure 2D, is that in accordance with the present embodiment, the deflected light propagation course does not pass through optical switches.

Thus, each optical switch is operative as a 1X2 switch, having a single input optical fiber 133_i (where i designates the light propagation) and two outputs optical fibers, 137_i for the deflected course, and 139_i for the undeflected course. Both sets of optical fibers, 137_i and 139_i are directed to optical couplers. An optical coupler 123B couples the undeflected light propagations to optical fiber 130, which continues to power the data network. An optical coupler 123B couples between the plurality of optical fibers, 137_i such as optical fibers 137_2, 137_4, 137_5, 137_6, and 137_8 and the PE associated with optical switch array 120.

In accordance with a preferred embodiment of the present invention, optical switches, 122, 124, 125, 126, and 128 are as taught by US Patent 6,542,264, to Agranat, et al., dated April 1, 2003, whose disclosure is incorporated herein by reference. US Patent 6,542,264 teaches an optical switch, comprising a paraelectric photorefractive material, in which a latent hologram is stored. The reconstruction, or activation of the hologram is controllable by the application of an externally applied electric field, so that in the absence of an external electric field, light propagations, which impinge on the material, do not sense the hologram. The application of an electric field causes the hologram to be reconstructed, and light propagations, which meet Bragg's condition, are diffracted.

The reconstructed hologram is formed by spatial modulation of the refractive index of the paraelectric photorefractive material, which arises from the quadratic electro-optic effect induced by the combined action of a spatially modulated space charge within the paraelectric photorefractive material and a single externally applied electric field. Alternatively, the reconstructed hologram may be formed by spatial modulation of the refractive index arising from a quadratic electro-optic effect induced by the combined action of a spatially modulated low frequency dielectric constant and a single externally applied electric field.

It will be appreciated that other optical and electroholographic switches may similarly be used.

In accordance with the present invention, the optical switches may be electroholographic switches as taught by any one of the following references whose disclosure is incorporated herein by reference: 1. A. J. Agranat, "Optical Lambda-Switching at Telecom Wavelengths Based on Electroholography", in: IR Holography for Optical Communications – Techniques, Materials and Devices, Pierpaolo Boffi, Davide Piccinin, Maria Chiara Ubaldi (Eds.), (Springer Verlag series on Topics in Applied Physics 2002); and 2. M. Balberg, M. Razvag, E. Refaelli, and A. J. Agranat, "Electric field multiplexing of volume holograms in paraelectric crystals" Applied Optics 37, pp. 841 - 847 (1998).

Referring further to the drawings, Figures 2F and 2G schematically illustrate another geometry, using a single electroholographic switch 127, in place of array of optical switches 120 of Figures 2B - 2C and 2D – 2E. Single electroholographic switch 127 contains a plurality of holograms, adapted to deflect different light propagations at different electric fields. A variable electric source 160 is associated with single electroholographic switch 127, for applying a different electric field, each time, responsive to an input signal from the PE associated with single electroholographic switch 127. This method is known as electric field multiplexing (EFM).

Single electroholographic switch 127 may operate by Bragg's detuning, for example as taught in US Patent 5,684,612 to Wilde et al., dated Nov. 4, 1997; and M. Balberg, M. Razvag, E. Refaelli, and A. J. Agranat, "Electric field multiplexing of volume holograms in paraelectric crystals" Applied Optics 37, pp. 841 - 847 (1998), both of whose disclosures are incorporated herein by reference.

Preferably, the response time for the optical switches is in the order of 1 – 10 nanoseconds.

Referring further to the drawings, Figure 2H schematically illustrates laser power grid 100 of a single wavelength, for example, for use with data networks transmitting at a single wavelength.

Referring further to the drawings, Figures 3A and 3B schematically illustrate a processing element (PE) 200 and a data network 210 employing WDM multiplexing, and preferably also incorporating wavelength addressing, using laser power grid 100, in accordance with the present invention.

It will be appreciated that the PE may a chip, a board, a cabinet, or even a routing switch.

In essence, laser power grid 100 and data network 210 of the present invention replace tunable laser 40 of the prior art, as can be seen by comparing PE 10 (Figure 1A) of the prior art, and PE 200 (Figure 3A) of the present invention.

Thus, data network 210 (Figure 3B) is similar in operation to data network 150 of the prior art, but is free from the use of tunable lasers. Instead, one array of fixed wavelength lasers, namely laser power supply station 110, powers the whole network.

As seen in Figure 3A, PE 200 includes processing unit 30, transmitter 20 and wavelength addressed receiver $90[\lambda_0]$. Processing unit 30 communicates to transmitter 20 an information defined by E_i ; λ_i, wherein E_i relates to an electronic data to be transmitted, and λ_i is the address of the receiving PE, at a specific instant.

Transmitter 20 communicates the wavelength designation λ_i to optical switch array 120. In response, a light propagation of wavelength λ_i is deflected. Additionally, transmitter 20 communicates the electronic data E_i to a modulator 60, which modulates the light propagation of wavelength λ_i so as to produce a data packet $50_i;\lambda_i$ containing electronic information E_i and addressed to a PE whose receiving address is λ_i.

When information is received, wavelength addressed receiver $90[\lambda_0]$ communicates the received data, for example, $59_n;\lambda_0$, to processing unit 30.

Figure 3B illustrates data network 210 having a plurality of PEs of the type described in Figure 3A, denoted, PE 202, PE 204, PE 205, PE 206, and PE 208, having processing units 32, 34, 35, 36, and 38, respectively, transmitters 22, 24, 25, 26, and 28, respectively, optical switch arrays 142, 144, 145, 146, and 148, respectively, modulators 62, 64, 65, 66, and 68, respectively, and wavelength addressed receivers $92[\lambda_5]$, $94[\lambda_6]$, $95[\lambda_4]$, $96[\lambda_8]$, and $98[\lambda_2]$, respectively, the wavelength addressed receivers communicating their received data to processing units 32, 34, 35, 36, and 38, respectively.

Accordingly, a plurality of data packets, $52_i;\lambda_2$, $54_i;\lambda_4$, $55_i;\lambda_5$, $56_i;\lambda_6$, and $58_i;\lambda_8$, each issuing from its respective PE, are coupled to optical coupler 70 and transmitted, by WDM.

Optical-wavelength demultiplexer 80 decouples the data packets by wavelengths, and each is routed to its wavelength address.

Data network 210 of the present invention is advantageous over data network 150 of the prior art for the following reasons:

5　　　i.　　　speed:　data network 210 of the present invention is faster - the response time of the optical switches may be 10 nanoseconds or less, compared to about 50 nanoseconds, for the tunable laser

　　　ii.　　　waste heat:　because laser power supply station 110 is external to the data network, heat production is minimized so less heat needs to be dissipated, within 10　the data network surroundings; and

　　　iii.　　　cost:　the optical switch arrays are generally cheaper then the tunable lasers.

Referring further to the drawings, Figure 4 schematically illustrates a data network 220, employing WDM multiplexing, and preferably also incorporating 15　wavelength addressing, wherein the PEs are distributed in more than one location.

In accordance with the present example, some PEs are located at a location 220A, and some PEs are located at a location 220B, wherein each PE may communicate with any other PE in both 220A and 220B.

For the present example, the architecture of Figure 3B is unsuitable, since 20　single optical fiber 75 cannot serve both 220A and 220B. However, the design and operation of individual PEs 202, 204, 205, 206, and 208, as illustrated in Figure 3A, is not affected by their location.

It will be appreciated however, that when two or more locations are employed, each location may be served by a dedicated laser power grid. Alternatively, when the 25　locations are close to each other, a single laser power grid may be used.

When a data network is spread over several locations, a total of five steps, three steps of coupling and two steps of optical wavelength demultiplexing, are required, as follows:

1.　　　As a first step, data packets issuing from each location, such as locations 220A 30　and 220B, are coupled to single fibers, such as fibers 75A and 75B, respectively, which lead from each location to a central location.

2.   As a second step, at the central location, data packets arriving in single fibers from each location, such as single fibers 75A and 75B, are coupled by central optical coupler 70, to central optical fiber 75.

3.   As a third step, at the central location, central optical wavelength demultiplexer 80 decouples the data packets in accordance with their wavelengths. These are then routed by wavelength, to the destination, for example, location 220A or 220B.

4.   As a fourth step, at the central location, data packets heading to common locations are coupled by destination, to a single fiber for each designation, for example, by couplers 70C and 70D to single fibers 75C and 75D, respectively.

5.   As a fifth step, at each destination, optical wavelength demultiplexers, such as demultiplexers 80A and 80B, decouple the data packets, in accordance with their wavelengths.

It will be appreciated that this architecture does not increase in steps as the number of locations increases.

Referring further to the drawings, Figures 5A and 5B schematically illustrate a multi-cluster data network, employing WDM multiplexing, and preferably incorporating wavelength addressing, using a laser power grid, in accordance with the present invention.

Multi-clustering provides a means for wavelength addressing even as the number of PEs is greater than the number of wavelengths of laser power grid 100 - the data network may be scaled up to a size equal to or less than the number of wavelengths times the number of clusters.

Figure 5A schematically illustrates a PE 230, wherein processing unit 30 communicates to transmitter 20 an information defined by E_i ; λ_i; I_i, wherein E_i relates to an electronic data to be transmitted, as before (Figures 1A and 3A) λ_i is the address of the receiving PE, within a specific cluster, and I_i is the destination cluster. In the present example, transmitter 20 designates cluster 2 for the specific data packet defined by E_i ; λ_i.

Multi-clustering requires two steps of coupling and a single step of optical wavelength demultiplexing:

1.   As a first step, the data packets from each cluster are coupled by destination cluster, as follows:

i.   all data packets from cluster 1, heading to cluster 1, are coupled, by a coupler 70(1,1), to an optical fiber 75(1,1);

ii.   all data packets from cluster 1, heading to cluster 2, are coupled, by a coupler 70(1,2), to an optical fiber 75(1,2);

iii.   all data packets from cluster 2, heading to cluster 1, are coupled, by a coupler 70(2,1), to an optical fiber 75(2,1); and

iv.   all data packets from cluster 1, heading to cluster 1, are coupled, by a coupler 70(2,2), to an optical fiber 75(2,2).

2.   As a second step, the optical fibers leading to a same destination cluster are coupled, as follows:

i.   the two optical fibers leading to cluster 1, namely 75(1,1) and 75(2,1) are coupled to an optical fiber 75(1), by a coupler 70(1) ; and

ii.   the two optical fibers leading to cluster 2, namely 75(1,2) and 75(2,2) are coupled to an optical fiber 75(2), by a coupler 70(2).

3.   As a third step, optical wavelength demultiplexing takes place within each cluster, as follows:

i.   optical wavelength demultiplexer 80(1) demultiplexes data packets arriving by optical fiber 75(1), in accordance with wavelengths; and

ii.   optical wavelength demultiplexer 80(2) demultiplexes data packets arriving by optical fiber 75(2), in accordance with wavelengths.

It will be appreciated that this architecture does not increase in steps as the number of clusters increases.

It will be appreciated that many combinations of the architectures of Figures 3A – 5B are also possible, depending on the circumstances, and are within the scope of the present invention. For example, clusters may be geographically separated, or adjacent to each other, a single cluster may be split among several geographical location, all the receiving PEs may be in one location, and all the transmitting PEs in another, and many others.

Referring further to the drawings, Figures 6B and 6B schematically illustrate an electroholographic switch, in accordance with the present invention.

It may happen that two or more PEs are to transmit at the same wavelength, simultaneously. In order to provide laser power for such occurrences, from laser power grid 100, fractional deflection may be employed.

The electroholographic switch it inherently analog. Hence it is possible to vary the level of the applied voltage, so as to determine the fraction light propagation that is deflected, leaving the remainder to propagate unaffected.

Figures 6A and 6B illustrate switch 125, seen also in Figure 2C, for providing fractional deflection f_1 to the light propagation of wavelength λ_5. The remaining fraction f_2 continues to power the network.

This procedure may be employed when the power level of laser power grid 100 is sufficient. Each PE may be adapted to monitor the power of the light propagation at the optical switch associated with it, and deflect only the necessary amount of power. For example, a first PE requiring λ_5, may deflect 1/3 of the power, allowing the remainder 2/3 to continue down the grid. A second PE may deflect ½ of the remainder. A third PE may take 100% of the remainder. This may be done by adjusting the voltage applied to the optical switch, to vary the diffraction efficiency. In this manner, a single light propagation may be used by three PEs, simultaneously.

Discussion

The fact that the phenomenal capabilities of optical communication are a preferred solution to meet the exponentially demand for bandwidth in computer systems is commonly accepted. In particular, several groups in both the industry and academia are currently considering wavelength addressing based on tunable lasers. The applications that are being considered include packets distribution in routers, communication between boards in servers, burst switching in storage area networks, and inter cabinet parallel communication in high performance computers. The projected timetable for these applications varies between four years (servers and storage area networks), through five years (routers), and eight years (high performance computers). In contrast, the projected development of the laser power grid concept of the present invention, from preliminary feasibility demonstration to design win is expected to be accomplished within three to four years.

The laser power grid, described hereinabove, in conjunction with Figures 2A – 6, exports a basic, even trivial concept from the electronic arena to the optical arena. In electronic circuits, power lines that carry electrical power, supplied from an external power source, such as a battery or a power supply, distribute the electrical energy necessary to operate the various components that constitute the circuit. The

idea at the basis of the laser power grid is to supply the optical energy that is needed to operate a massive optical communication network from a laser sources operative as a power source, and to distribute this energy in the data network by a grid analogous to a power grid.

5   Thus, by using one set of fixed wavelength lasers the entire network can be operated. This architecture obviates several of the problems that characterize the "tunable lasers architecture" of Figure 1A. First, one set of fixed lasers serves the entire network rather than a tunable laser for each transmitting port. The lasers are operated in continuous-work cw mode at a single wavelength so that the cumbersome

10   operation of fast random hopping of the tunable laser to a new wavelength for each data packet is avoided. Additionally, the power distribution by means of the electroholographic switching station is fast. Furthermore power dissipation at the cabinet is a major handicap of extending the performance of complex computer systems. An additional advantage of the laser power grid concept is that a substantial

15   fraction of the power is dissipated outside the data network surroundings. Moreover, mean time between failures (MTBF) for the laser power grid is expected to be less than that for tunable lasers.

The concept of the laser power grid appears promising for harnessing optical communication to supply the bandwidth necessary for developing the next

20   generations of computer systems, in particular for board-to-board and chip-to-chip applications. As has been shown, the implementation of the laser power grid concept can be accomplished by different technologies of optical switches.

In addition, the concept of the laser power grid bears general significance for harnessing the strength of optical communication to both telecom and datacom

25   applications. For example in circuit switching applications, concentrating the light source in one location and managing the central offices in a ring by passive electrooptic devices may result in substantial reduction of operation expenses of the ring. Such applications can be deployed on the existing infrastructure employing WDM technology.

30   Since the laser light propagations in laser power grid 100 (Figure 2A) carry optical power and not data, multimode fibers may be used, rendering the power loss in coupling and decoupling to the optical switches minimal. It should also be noted that laser power grid 100 can be constructed of a ribbon of fibers, or by a single fiber.

Laser power grid 100 obviates the need for tunable lasers in wavelength addressing schemes and makes wavelength addressing possible even for very fast burst switching in networks with many PEs, including inter-board and inter-chip applications.

5   It should be emphasized that the switching station 140 (Figures 2A – 6) need not necessarily be based on the principle of electroholography. However, electroholographic switches seem to be the most cost effective devices for implementing the laser power distribution.

Electroholography is a wavelength selective optical switching method based
10   on governing of the reconstruction process of volume holograms by means of an electric field. A detailed review of electroholography and its application to wavelength selective switching can be found in A. J. Agranat, "Optical Lambda-Switching at Telecom Wavelengths Based on Electroholography", in: IR Holography for Optical Communications – Techniques, Materials and Devices, Pierpaolo Boffi,
15   Davide Piccinin, Maria Chiara Ubaldi (Eds.), (Springer Verlag series on Topics in Applied Physics 2002).

The basic building block of the electroholographic device is the electrically controlled Bragg grating (ECBG) as presented schematically in Figures 1B and 1C. When the electric field is off the grating is in a latent state. In this state (Figure 1B),
20   the grating is transparent so that an incident light wave propagates through the grating unaffected. When the electric field is turned on (Figure 1C), the grating is activated. In the 'on' (active) state an input beam will be diffracted, provided it fulfills Bragg condition, as shown for the beam of wavelength λ_1 in Figure 1C. An input beam that does not fulfill Bragg condition will propagate through the active grating unaffected,
25   as shown for the beam of wavelength λ_2 in Figure 1C. Thus, an electrically controlled grating possesses the basic feature for functioning as a wavelength selective switch.

Electroholography is based on the voltage controlled photorefractive effect at the paraelectric phase. The ECBG is a space charge Bragg grating or a volume hologram stored in a volume of a paraelectric crystal by the photorefractive process.
30   Since the electrooptic effect at the paraelectric phase is quadratic, the application of a uniform electric field on the crystal causes the refractive index (birefringence) grating induced by the space charge grating to be directly proportional the applied field. Thus, the switching operation involves the activation of an index grating that is stored in a

latent form as a space charge grating. An alternative electroholographic switching mechanism is by use of the dielectric photorefractive effect where the latent grating is stored in the form of a dielectric constant grating. Here the application of a uniform electric field induces a (low frequency) polarization grating that couples with the uniform polarization induced by the field to form the index grating.

In principle, the electroholographic switches described in US Patent 6,542,264, to Agranat, et al., dated April 1, 2003, whose disclosure is incorporated herein by reference, are suitable as the optical switches of Figures 2A - 6. However, these switches are tailored for circuit switching applications in telecomm networks, and may not be optimal for the present application.

An alternative is a new electroholographic switch tailored for the laser power grid, described in M. Balberg, M. Razvag, E. Refaelli, and A. J. Agranat, "Electric field multiplexing of volume holograms in paraelectric crystals" Applied Optics 37, pp. 841 - 847 (1998)), whose disclosure is incorporated herein by reference. It is based on the principle of electric field multiplexing.

Electric field multiplexing (EFM) of volume gratings enables to selectively restore a single grating from an ensemble of gratings that are superimposed in the same volume. Selective restoration is accomplished by applying an electric field at a level that tunes the Bragg condition of the selected wavelength. EFM is less suitable for wavelength-selective data switching, as in US Patent 6,542,264, because only a fraction of the beam of the selected wavelength is deflected, rendering this wavelength unusable further along the network.

However, in the laser power grid, at each PE, the power distributor transfers a fraction of the power at the selected wavelength to the data network. The remaining power at the selected wavelength continues in the power grid. Hence, EFM can be used as the wavelength selection method with laser power grid 100, as has been described in conjunction with Figures 6A – 6B.

It will be appreciated that electroholography may be achieved by Bragg's detuning, for example as taught in US Patent 5,684,612 to Wilde et al., dated Nov. 4, 1997, whose disclosure is incorporated herein by reference. Wilde et al., teach a hologram with a dynamically controlled diffraction efficiency and enhanced signal-to-noise ratio, recorded in ferroelectric photorefractive materials, such as strontium barium niobate ($Sr_x Ba_{1-x} Nb_2 O_6$) (SBN), BSTN, SCNN, PBN,

BSKNN, BaTiO.sub.3, LiNbO.sub.3, KNbO.sub.3, KTN, PLZT and the tungsten bronze family. The diffraction efficiency of the hologram is dynamically controlled by applying an electric field along the polar axis of the ferroelectric photorefractive recording medium. Electrically controlled diffraction is used in conjunction with

5   hologram fixing and operation of the material at a temperature in the vicinity of or above its Curie temperature to additionally provide prolonged, low-noise readout. The general methods for recording and reconstructing a hologram (or a set of multiplexed holograms) using these techniques is disclosed. A plurality of configurations employing the improved hologram are disclosed, including an optical crossbar switch

10   in guided-wave and free-space formats that can function as a component in a variety of parallel optical processing systems, a reconfigurable dynamic wavelength filter, and a page-based holographic data storage system. However, the system of Wilde et al., which is based on Bragg's detuning, applies only to the embodiment of Figures 2A and 2B, hereinbelow, where each optical switch is controlled individually.

15   Alternatively, the electroholographic switches may operate by Bragg's detuning, wherein the holograms are operative at no electric field and are detuned by the application of an external electric field; the application of an electric field is the "off" mode, and no light is deflected. With the removal of the electric field, all the holograms are tuned, and all the light propagations may deflect, simultaneously. This

20   method may be applied for the plurality of switches shown in Figures 2A and 2B, or to the single switch containing multiple holograms, shown in Figure 2C.

Electroholography combines several unique features. The basic electroholographic switching operation is the reconstruction of a volume grating (hologram), that requires that the Bragg condition be satisfied, and therefore it is

25   wavelength selective. In addition the applied field governs the efficiency of the reconstruction. Consequently electroholography includes grouping, multicasting, laser power management and non-intrusive data monitoring as an integral part of the switching operation. Since the electrooptic effect is polarization dependent the switching operation is a priori not PDL free. However, by including diversity in the

30   architecture of the device the dependence of the switching efficiency on the polarization of the light can be removed.

The performance envelope of the basic electroholographic device is determined by the physical dimensions of the implemented grating and input beam.

The switch is inherently independent of the data throughput rate. BER in a switch operating at 40Gb/s where measured to be 10^{-13}. In a device that is a cube of 1.8^3 mm^3 the minimum net insertion loss is 0.5 dB per switching operation. The minimum loss when a beam propagates through a latent grating is 0.2% primarily due to losses by the antireflective coating at the faces of the crystal. The PDL in a device that includes diversity architecture is less than 0.2 dB and the PMD is less than 0.05 ps. Finally, the temporal behavior of the switch is determined by the dielectric response of the crystal at the operating temperature. Response time of less than 10 ns was measured in an electroholographic switch. The basics of electroholography as a well as a detailed discussion of the various functions and reliability issues are given in detail in A. J. Agranat, "Optical Lambda-Switching at Telecom Wavelengths Based on Electroholography", in: IR Holography for Optical Communications – Techniques, Materials and Devices, Pierpaolo Boffi, Davide Piccinin, Maria Chiara Ubaldi (Eds.), (Springer Verlag series on Topics in Applied Physics 2002).

It will be appreciated that power losses may take place along laser power grid 100, and it may be necessary to supply additional power to compensate for the loss along the grid and in its components.

It is expected that during the life of this patent many relevant laser power grids will be developed and the scope of the present invention is intended to include all such new technologies a priori.

As used herein the term "about" refers to ± 10 %.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or

patent application was specifically and individually indicated to be incorporated herein by reference.